

Feasibility and trajectory study of anterior transarticular crossing screw placement for atlantoaxial joint instability: a cadaveric study and description of a novel technique

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Abstract

Purpose In unique clinical situations where C1–C2 anterior transarticular screw (ATS) fixation is not available or has failed, an anterior transarticular crossing screw (ATCS) with transcorporeal pathway of the screws inside the contralateral promontory of C2 may enhance the stabilization and achieve atlantoaxial arthrodesis. The present study was to describe a novel technique of ATCS fixation for atlantoaxial joint instability and its applied anatomy, and compared it with ATS fixation method.

Methods Direct measurements using digital calipers and a goniometer were conducted on 30 pairs of dried human C1 and C2 vertebrae. The ATS and ATCS with screws (Φ 4.0 mm) were performed on 11 fresh cervical spine specimens. The screw lengths in the C1 and C2, and screw entry angles of the ATS and ATCS were measured, respectively. Cadaver specimens were dissected to observe the incidence of violation to the important structures surrounding the ATS and ATCS fixation technique.

Results There was enough osseous space for ATCS placement. The lateral and incline angle of the ATCS was 36.2° and 28.7°, respectively. Screw purchase in C2 of the ATCS (25.6 mm) was greater than that of the ATS (11.4 mm). The ATCS C1 purchase (14.8 mm) was similar to the ATS C1 purchase (14.9 mm). No violation to the

vertebral artery groove, the spinal canal or the atlanto-occipital joint was observed after the ATCS placement.

Conclusion Anterior transarticular crossing screw is a feasible and viable option for atlantoaxial fixation in selected cases. This technique achieved remarkable longer screw purchase and could enhance the atlantoaxial stability.

Keywords Atlas · Axial · Crossing screw · Anterior approach · Transarticular screw

Introduction

Anterior transarticular screw (ATS) fixation for atlantoaxial joint instability was first described by Barbour [1] in 1971. In 1998, Lu et al. [2] conducted an anatomic study for ATS fixation. There had been no further studies on the topic until Reindl et al. [3] reported on the technique using a standard Smith-Robinson approach in 2003. Two years later, the same team performed a biomechanical study and confirmed the effectiveness of this technique in atlantoaxial stabilization [4]. Since then, some modification in surgical techniques using minimally invasive or percutaneous surgical procedures have been reported [5–10].

There are, however, unique clinical situations in which these common fixation techniques may be impossible, have already failed, or require supplemental fixation. Fracture of the anterior cortical rim of the C2 articular bone occurs rarely after ATS [7, 11]. Failed attempts at placement of ATS disrupted osseous anatomy are associated with fewer landmarks for reposition safe and effective ATS. For these unique salvage or rescue situations, the availability of anterior transarticular crossing screw (ATCS) with transcorporeal pathway of the screws inside the contralateral promontory of C2 may stabilize the the atlantoaxial joint.

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In this study, the authors propose a new technique of ATCS fixation for atlantoaxial fixation. Furthermore, the anatomic feasibility is assessed through a morphometric study on dry bones and an evaluation of screw trajectories using human cadaver spine specimens, and compared with ATS fixation method. To our knowledge, this technique has not been published in the English literature. As part of our ongoing research, we plan to evaluate the biomechanical implications of this new method.

Materials and methods

Measurements on the dry bones

Thirty pairs of dried atlas and axis specimens were provided by the Department of Anatomy. The race, sex, and age of the specimens were unknown. The detailed morphometric parameters related to ATCS were measured, including the left and right maximum widths and anteroposterior diameters of C1 inferior facet articular surface, the left and right lateral and medial heights of C1 lateral mass, the left and right angles of C1 inferior facet relative to the transverse plane (Fig. 1a, b). We also measured the C2 anterior and posterior vertebral body heights in the midline of vertebral body, the superior and inferior anteroposterior diameters of C2 vertebral body in the midsagittal plane, the C2 vertebral width at level of the inferior endplate (Fig. 1c, d).

All linear measurements were obtained using a digital caliper accurate to 0.1 mm (Mitutoyo Corp; Tokyo, Japan) and the angular measurements were recorded with a goniometer accurate to 1°.

ATCS placement on fresh cadaveric specimens

The craniovertebral junction segments (occiput–C4) from 11 fresh human cadaveric cervical spines were harvested (6 M/5F; mean age, 46 years; age range, 36–71 years) and frozen at –20 °C. Lateral and anteroposterior X-rays were taken to exclude obvious neoplastic, traumatic, congenital conditions, earlier surgery, or facet arthropathy. The spines were thawed on the day of surgery. The surgical dissection was performed on each specimen after the screw placement.

Screw entry points and trajectories

Two kinds of anterior transarticular screw fixations for atlantoaxial joint were determined (Fig. 2): ATS and ATCS. For ATS fixation, the entry point was set at just below the sulcus on the anterior body of the C2, located at the midpoint of the C2 body in the medial third of the

C1–C2 facet joint [4, 12]. For ATCS fixation, the entry point was set at a point 5 mm cranial to the anterior edge of the C2 end plate and 3–5 mm lateral from the midline to the contralateral side, to provide an allowable distance between the screw head and the C2–C3 intervertebral disc to prevent adjacent level ossification development. In order to reduce the damage to the specimen, ATCS and ATS were randomly placed at left or right side once on each specimen.

The ATS and ATCS trajectories were determined using the landmarks visible on anteroposterior and lateral x-rays. On the anteroposterior view, screw trajectories were aimed at the superolateral corner of C1 superior articular process, leaving 2–3 mm clearance from lateral margin of the lateral mass (Fig. 3, left). Then, the angle α , the ideal lateral angle of ATS and ATCS placement relative to the sagittal plane were measured. On the lateral view, the trajectories of ATS and ATCS were aimed at a point on the line between the superoposterior corner of C1 superior articular process and the superior end of the anterior arch, with 2–3 mm clearance from posterior margin of the superior articular process (Fig. 3, right). Moreover, the angle β , the ideal incline angle of the two screw placement relative to coronal plane were measured. After the screws were inserted into fresh cadaveric specimens, the actual angle α and β of ATS and ATCS were also measured on anteroposterior and lateral X-ray images, respectively, as well as the actual entry points of ATCS and ATS lateral from the midline of the C2 vertebrae.

Screw length and lengths of C1/C2 purchase

The diameter of the both screws was 4.0 mm, the same diameter used in previous clinical and biomechanical studies [4, 10, 13]. The maximum allowable screw lengths in the absence of any cortical breach were measured with a depth gauge. The screws were removed, the specimens were disarticulated from the occiput and C2, and the anterior soft tissues were removed. Incidence of violation to the vertebral artery (VA) groove, the spinal canal, or the atlanto-occipital joint was observed for the two fixation techniques. In addition, the length of C1 purchase was measured from the cortical margin at the inferior articular surface of C1 to the end point. The length of the C2 purchase was measured from the screw entrance to the cortical margin at the C2 superior articular surface. These measurements were done for ATS and ATCS, respectively.

Statistical analyses

The results were presented as the mean \pm standard deviation. Paired *t*-test was used to compare the left and right anatomic parameters of C1 vertebral body, as well as

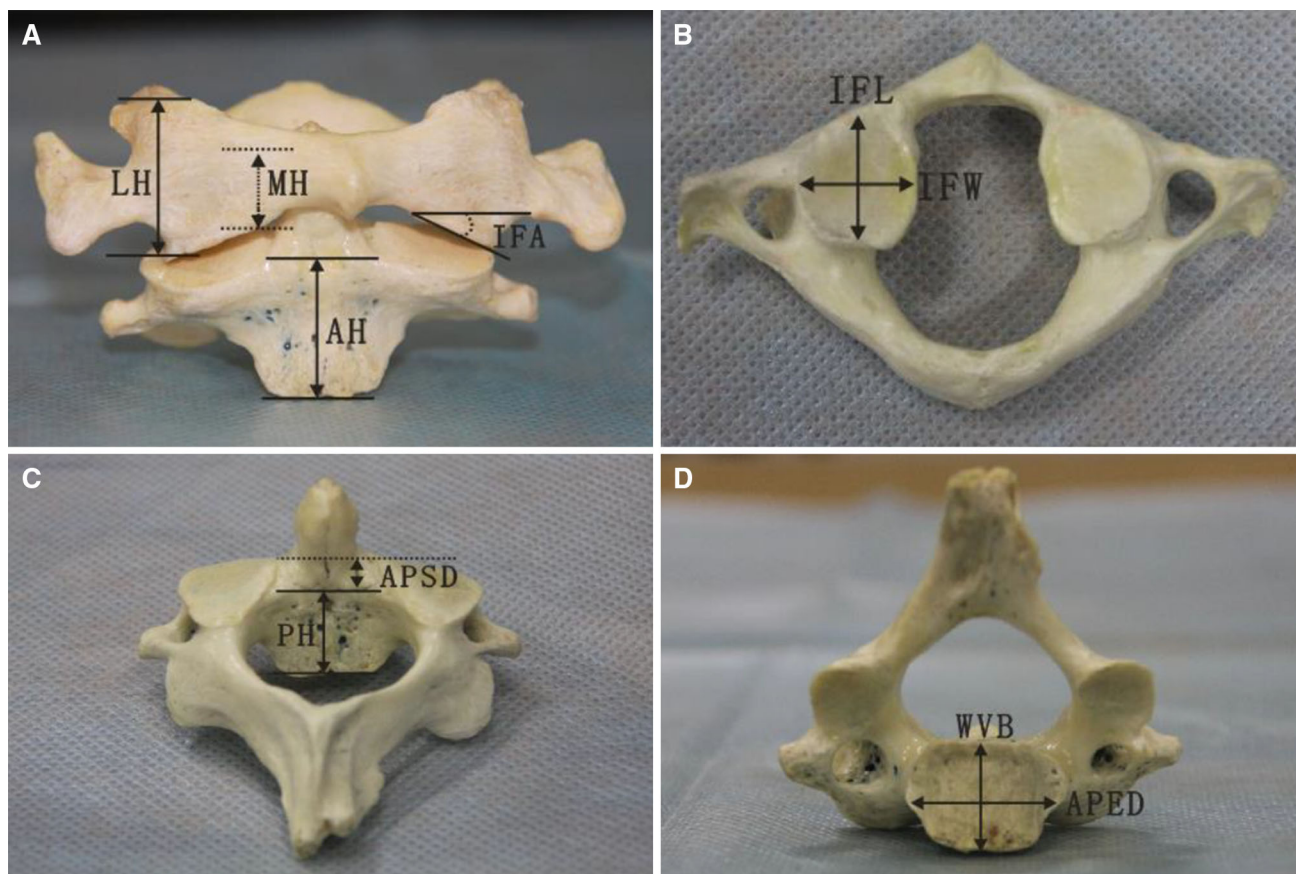


Fig. 1 Linear and angular measurements of C1 and C2 vertebrae. **a** *LH* lateral height of lateral mass, *MH* medial height of lateral mass, *IFA* inferior facet angle relative to transverse plane, *AH* anterior height of vertebral body. **b** *IFW* inferior facet width, *IFL* inferior facet

length. **c** *PH* posterior height of vertebral body, *APSD* anteroposterior endplate diameter. **d** *WVB* width of vertebral body, *APED* anteroposterior superior vertebral diameter

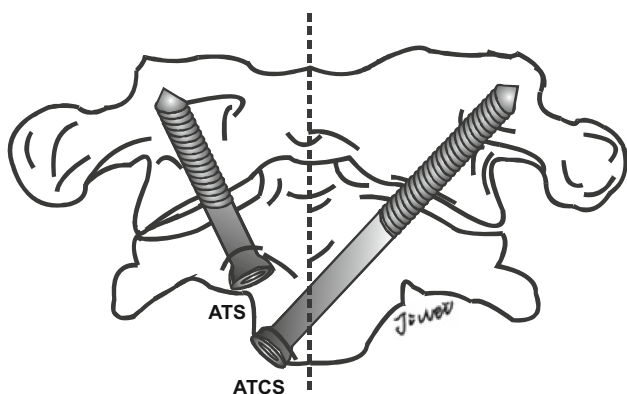


Fig. 2 Artist's illustrations showing the anterior transarticular screw (ATS) fixation and the anterior transarticular crossing screw (ATCS) fixation

dimensions and angles between ATS and ATCS. The statistical software used was SPSS version 13.0 (Chicago, IL). Statistically significant differences were set at a $p < 0.05$.

Results

Measurements on the dry bones

All linear and angular measurements and statistical differences between the left and right are shown in Tables 1 and 2. There were no statistical differences in any measurements between sides. The angle of the C1 inferior facets relative to the transverse plane was $29.6^\circ \pm 5.0^\circ$. The lateral and medial height of later mass was 18.2 ± 2.5 mm and 10.0 ± 2.3 mm, respectively. The inferior facet width and inferior facet length was 16.0 ± 1.7 mm and 17.3 ± 1.7 mm, respectively.

The C2 body height was greater in the anterior (19.5 ± 1.6 mm) than that in the posterior (16.2 ± 1.5 mm). The width of C2 inferior endplate was 19.7 ± 2.4 mm. The anteroposterior diameter of C2 body was greater at the inferior endplate level (17.1 ± 1.5 mm) than that at the superior vertebral level (10.9 ± 1.7 mm) (Table 2).

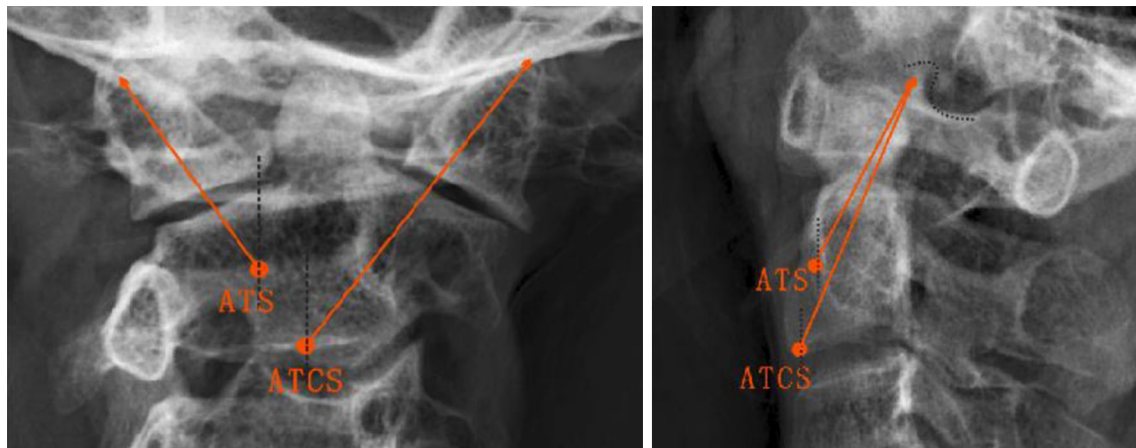


Fig. 3 Trajectories of ATS and ATCS are shown on anteroposterior (left) and lateral radiographs (right). (left) All screws are aimed at the superolateral corner of C1 superior articular process; (right) All

screws are aimed at the superoposterior corner of C1 superior articular process (around dot). ATCS anterior transarticular crossing screw, ATS anterior transarticular screw

Table 1 Anatomic parameters of C1 vertebral body

		Mean	SD	Minimum	Maximum
LH (mm)	L	18.3	2.6	13.0	24.5
	R	18.1	2.3	12.8	24.1
MH (mm)	L	10.2	2.5	5.0	15.2
	R	9.8	1.8	5.1	14.9
IFW (mm)	L	16.1	1.7	12.5	19.2
	R	15.9	1.6	12.2	18.9
IFL (mm)	L	17.7	1.7	14.5	21.3
	R	16.8	1.8	14.4	21.7
IFA (°)	L	29.1	4.9	20.8	40.0
	R	30.2	5.0	21.5	41.2

SD standard deviation, LH lateral height of lateral mass, MH medial height of lateral mass, IFW inferior facet width, IFL inferior facet length, IFA inferior facet angle relative to transverse plane, L left, R right

Table 2 Anatomic parameters of C2 vertebral body

	Mean	SD	Minimum	Maximum
AH (mm)	19.5	1.6	17.2	23.8
PH (mm)	16.2	1.5	14.1	21.0
APED (mm)	17.1	1.5	14.5	20.1
WVB (mm)	19.7	2.4	14.6	25.6
APSD (mm)	10.9	1.7	7.6	13.7

SD standard deviation, AH anterior height of vertebral body, PH posterior height of vertebral body, APED anteroposterior endplate diameter, WVB width of vertebral body, APSD anteroposterior superior vertebral diameter

ATCS placement on fresh cadaveric specimens

The ATCS and ATS were inserted successfully into all specimens without any violation to the VA groove of C1

and C2, or the spinal canal. Neither was there any violation to the atlanto-occipital joint. The actual entry points of ATCS and ATS lateral from the midline was 5.0 ± 1.1 mm and 13.0 ± 1.5 mm, respectively.

The ideal lateral and incline angles was $38.3^\circ \pm 4.1^\circ$ and $30.7^\circ \pm 2.9^\circ$ for the ATCS, and $29.6^\circ \pm 2.7^\circ$ and $34.3^\circ \pm 2.5^\circ$ for the ATS, respectively. There was no statistical difference between the ideal and the actual screw angulations ($p < 0.05$). After the screws were inserted (Fig. 4), the actual lateral angle of the ATCS relative to sagittal plane was greater than that of the ATS measured on anteroposterior X-rays. On the contrary, the actual incline angle of the ATCS relative to coronal plane was smaller than that of the ATS (Table 3).

The screw lengths and lengths of C1/C2 purchase were summarized in Table 3. Overall, the ATCS length (40.4 ± 2.2 mm) was significantly longer than the ATS length (26.4 ± 3.1 mm) ($p < 0.001$). The ATCS length of C1 purchase was 14.8 ± 1.6 mm, and similar to the ATS length (14.9 ± 1.5 mm). The ATCS length of C2 purchase was 25.6 ± 1.6 mm, and longer than the ATS length (11.4 ± 1.7 mm) ($p < 0.001$).

Discussion

Two types of ATS placements are used for open surgery and percutaneous minimal invasion surgery with different screw entrances. For the open surgery, the entry point was set at just below the sulcus of the anterior C2 body, and located at the midpoint of C2 body and the medial third of C1–C2 facet joint. The screw was inserted into the C2 body 20° medially on the anteroposterior view and 30° the cephalic on the lateral view, crossing the atlantoaxial joint just anterior to the midpoint [4]. The percutaneous

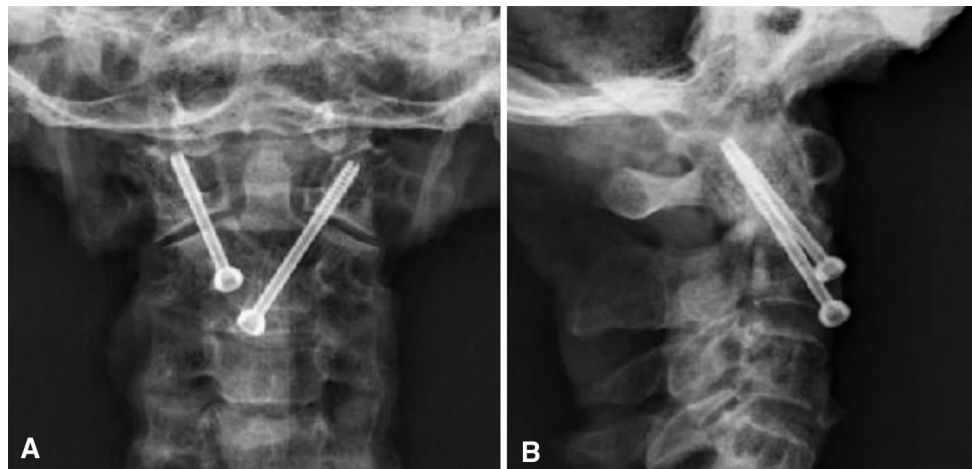


Fig. 4 The anterior transarticular crossing screws fixation is shown on anteroposterior (a) and lateral radiographs (b), respectively

Table 3 Screw length and angulations measured on 11 fresh human cadaveric cervical spines

	ATCS	ATS
Screw length (mm)	40.4 ± 2.2 (36.7–45.0)	26.4 ± 3.1* (21.0–32.0)
C1 purchase (mm)	14.8 ± 1.6 (11.7–17.1)	14.9 ± 1.5 (12.0–17.3)
C2 purchase (mm)	25.6 ± 1.6 (22.5–28.2)	11.4 ± 1.7* (9.0–14.7)
α (°)	36.2 ± 5.0 (28.4–45.1)	28.7 ± 4.0* (21.2–35.1)
β (°)	28.9 ± 3.8 (24.3–33.7)	32.6 ± 2.9* (26.5–36.1)

Values are mean ± standard deviation

ATCS anterior transarticular crossing screw, ATS anterior transarticular screw

* Indicates difference from the ATCS ($p < 0.05$)

ATS trajectory passed through the middle of the C1–C2 facet joint, and the recommended entrance was at the inferior border of the C2 body and off the midline 5 mm to 10 mm, with 20° to 30° medial in the anteroposterior view and 20° to 28° cephalic in the lateral view [9]. Those screw angulations were similar to the actual angles of the ATS measured in this study.

However, there are unique clinical scenarios in which these common fixation methods may impossible and require supplemental fixation. Fracture of the anterior cortical rim of the C2 articular bone occurs rarely after ATS [7, 11]. When failed attempts at placement of ATS leave few landmarks for a safe and effective ATS reposition, the ATCS, as a salvage or rescue technique, may enhance the stabilization to the atlantoaxial joint.

Cacciola et al. [14] observed that the artery occupied, on average, 79 % of the VA groove on the inferior surface of C2 superior articular facet and approximately 57 % of the VA groove over the lateral part of C1 posterior arch. In this situation, the posterior transarticular screw fixation is impossible due to a potential risk of iatrogenic VA injury [15, 16]. Placement of ATS would be also difficult under such circumstances. For the patients with normal VA,

the ATS trajectory at the center of the C2 superior articular surface is considered as an ideal screw passageway. In contrast, when patients have high-riding VA (Fig. 5a), the ATS trajectory should be located anteriorly at the C2 superior articular surface with a smaller posterior entry angle in order to avoid the VA injury, but reduce the screw purchase to the C2 and increase the risk of screw cutout. However, ATCS placement for patients with high-riding VA (Fig. 5b) with the transcortical pathway of the screws inside the vertebral body of C2, increases screw purchase inside the C2 promontory with higher bone mineral density [17], and adds stability to the construct. In addition, the length of ATCS was remarkably longer. Therefore, it is anticipated that the ATCS fixation would be more stable than the ATS fixation.

As a salvage or rescue surgical technique for the treatment of atlantoaxial instability, the ATCS fixation technique was superior to the ATS fixation method as following aspects. Firstly, the ATCS passes through the promontory of anterior cortex C2 as a landmark, allows 4–6 mm off ipsilaterally as the entry point of ATCS, which can be identified easily. Secondly, the length of ATCS (40.4 mm) was remarkably longer than that of ATS

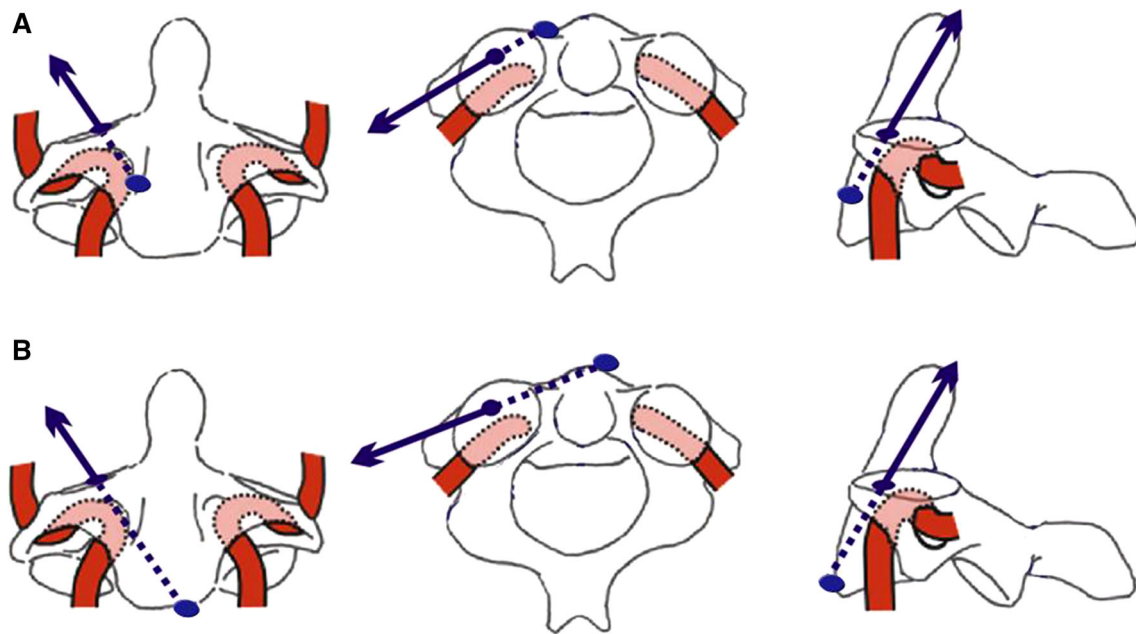


Fig. 5 Schematic drawings showing ATS (a) and ATCS (b) screw trajectories (blue arrow) in C2 with anomalous VA. ATCS anterior transarticular crossing screw, ATS anterior transarticular screw. VA indicates vertebral artery

(26.4 mm), which should be favor to resistance to screw pull-out. Thirdly, unilateral incision and exposure of the C2 avoids dissection of the contralateral soft tissue and VA injure. However, the ATCS fixation method as a novel screw fixation technique should be evaluated biomechanically in future.

The present anatomical study on the dry bones indicated that there was enough osseous space for the ATCS placement. The C1 inferior facet width and inferior facet length was 16 and 17 mm, respectively, which were greater than the diameter of the screw (4 mm). The width and anteroposterior diameter of the C2 body at the inferior endplate was 20 and 17 mm, respectively, which were enough for 2 screws inserted unilaterally. Theoretically, dimensions of the atlas and axis meet the requirement for bilateral ATCS placement,

The technique of the bilateral ATCS fixation may be advantageous in patients with two side screw cutout and insufficient bone at the anterior cortical rim of the C2 articular for an appropriate fixation, and in patients with two side high-riding arteries in the C2 segment. Moreover, bilateral ATCS using longer screws should enhance the fixation, which will be evaluated in our ongoing biomechanical study.

This technique should not be attempted without pre-operative CT evaluation to locate the vertebral arterial groove and to assess the feasibility in a given patient. Therefore, preoperative planning is essential, including combination of CT images with the proposed screw trajectory. Biplane

fluoroscopy is recommended intraoperatively. Furthermore, the sample size of the present study is small and may contribute to variation of the measured parameters.

Conclusions

Anterior atlantoaxial transarticular crossing screws appears feasible and may eventually be an alternative option for atlantoaxial fixation techniques. A biomechanical study of the anterior atlantoaxial transarticular crossing screws is necessary before clinical application. The remarkable longer screws used in this technique should be favor to resistance to screw pull-out.

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Compliance with ethical standards

Conflict of interest None.

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